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ABSTRACT

Cognitive science research offers hope for the development of innovative science teaching strategies that facilitate the development of optimally interconnected procedural and declarative knowledge networks. Improving students' neural networks should improve their abilities to think critically, reason logically, learn more efficiently, and solve more complex problems. The primary purpose of this research study was to reveal the intricacies of students' knowledge networks by constructing a cognitive network model associated with one particularly important problem-solving skill which is prediction. The central role of prediction in learning, problem solving, and scientific progress demands that its cognitive mechanisms be investigated and that teaching and learning strategies be developed with prediction as the focus. Fourteen prediction problem sheets, involving six different conceptual systems in biology and three different problem formats were administered to pre-service college students at a north central U.S. university enrolled in secondary or elementary methods classes. Each problem sheet required students to make a prediction, either in writing or on a graph, and then to explain their reasoning in writing. Qualitative data analysis followed a series of 4 steps, with each step building from the previous step: (1) identification of cognitive behavioral categories associated with successful and unsuccessful predictors; (2) construction of sequential behavioral transcripts of both successful and unsuccessful predictors; (3) identification of cognitive scripts for successful and unsuccessful predictors with attention to procedural and declarative knowledge; and (4) development of a cognitive-network model of prediction problem solving. An Explicit Prediction Teaching Strategy (EXPTS), developed from the model, encourages students to build a predictive framework of successful cognitive scripts. The mechanism of successful prediction problem solving was shown to be dependent upon a complex interplay between procedural and declarative knowledge as illustrated by a cognitive network model. This research represents one significant step toward developing problem-solving teaching strategies that take more advantage of the tremendous potential of "prediction power" in the science classroom. (KR)

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THE CONSTRUCTION AND APPLICATION OF A COGNITIVE-NETWORK MODEL OF PREDICTION PROBLEM SOLVING

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THE CONSTRUCTION AND APPLICATION OF A COGNITIVE NETWORK MODEL OF PREDICTION PROBLEM-SOLVING

Introduction

One of the highest priorities of science education concerns improving students abilities to think critically, reason logically, and ultimately, to solve problems. The success of science teachers toward this goal has been dismally ineffective in America as indicated by many national reports (National Commission for Excellence in Education, 1983; American Association for the Advancement of Science, 1988). National problems with drugs, disappearing natural resources, and the "homeless," among many others, may well be some of the results on an un-thinking society.

Cognitive science offers exciting hope for finding solutions to old and new problems. This relatively new field, combining cognitive psychology, artificial intelligence, computer science, neural biology, linguistics, philosophy, and science education, seeks to explain the information-processing intricacies of human knowledge and reasoning. The discipline has already started a great upheaval in how we view thinking, learning, teaching, and research in science teaching (diSessa, 1987). Perhaps we are approaching an era when a teacher, and possibly a computer tutor, will facilitate a students' learning at a capacity limited only by the physiological structure and function of the human brain.

Science teaching strategies of the future will allow students to build cognitive networks that link successful cognitive processing behaviors to relevant knowledge bases in ways most conducive for solving problems, achieving conceptual understanding, and facilitating subsequent learning. Both teachers and students will be in better positions to ask appropriate questions, provide appropriate feedback, and furnish appropriate information at the most opportune times.

Before this optimistic vision of the future can become reality, research must carefully examine the development, structure, and function of students' knowledge networks while they engage in a variety of intellectual tasks.

Information Processing Views of Problem Solving

Glass (1979) considers the problem solver to progress through three states of knowledge involving the identification of information about the problem, application of specific operators (to solve the problem), and a final goal state (the solved problem). An individual's representation of these knowledge states is termed the problem space (Newell & Simon, 1972). Lesgold (1988) refers to this problem space a "sort of maze of mental activity through which we must wander, searching for a solution." Understanding how students construct and manipulate knowledge within this problem space should be invaluable to developing effective problem-solving teaching strategies.

Representing and determining the problem space are two types of knowledge often referred to as procedural and declarative knowledge. Declarative knowledge centers on facts, concepts, data, and information. Procedural knowledge is knowing how to do something, such as how, where, and when to access, organize, and apply declarative knowledge. Procedural knowledge has been characterized as dynamic, automatic (unconscious), and requiring extensive practice to learn, while declarative knowledge is considered static, conscious, and easy to learn (Lohman, 1989). Cognitive

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science recognizes both types of knowledge to be essential for good problem solving (Anderson, 1980). Ultimately, the structure of the relationships between procedural and declarative knowledge will determine how information is received, stored, retrieved, and applied toward a problem-solution.

Although several cognitive behaviors associated with problem solving have been previously identified (Cook & Slife, 1985; Pizzini, Shepardson, & Abell, 1989; Roth, 1990; Sternberg, 1985a), and several generic models have been suggested for problem solving (Bransford & Stein, 1984; Joyce & Weil, 1986; Mayer, 1989; Pizzini, Shepardson, & Abell, 1989; Potts & StJohn, 1989; Simon, 1979) the details of the interplay between students' procedural and declarative knowledge networks remains largely a mystery. Models that explain the structure and function of multiple cognitive pathways and cognitive behaviors associated with these neural-knowledge networks need to be constructed for specific cognitive skills, problem types, and subject-matter domains. Then, teaching strategies that assist students in successfully building and applying knowledge networks can be developed, tested, and refined.

Objectives of the Study

Based on the above research needs, the goal of this research was to elucidate the intricacies of the relationships between students' procedural and declarative knowledge associated with one particularly important problem-solving skill, prediction. Specific objectives sought to:

- 1) Identify and compare students' declarative and procedural knowledge associated with successful and unsuccessful solutions to various types of prediction problems in biology.
- 2) Identify cognitive scripts, or sequential behavioral patterns, associated with successful and unsuccessful predictors.
- 3) Develop and describe a cognitive network model of the prediction problem solving process revealing connections between procedural and declarative knowledge bases
- 4) Suggest a generic teaching strategy for prediction problem solving

Importance of Prediction:

Prediction is central to learning, problem solving, and scientific progress (Good, 1989, March). In science education, prediction has been recognized as a science process skill (Doran, 1978), a problem solving skill (Gagne, 1965), and an essential component of scientific inquiry (Butts, et al. 1978). Prediction problem solving is a cognitive aptitude that allows us to survive and progress in a continually changing universe. The better predictors are given vantage points that often lead to important scientific discoveries, intelligent judgements on societal issues, and even substantial monetary gains. Improving prediction skills can help students construct better explanations and understandings of their worlds, and ultimately, can lead to better quality lifestyles.

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Recent research suggests that the major science teaching benefits to be gained through the use of prediction can be found in its ability to: a) expose students' prior conceptions (and misconceptions) to both teachers and students, b) establish cognitive commitments and motivation in students to follow up on their predictions with further learning and discussion, and c) facilitate students to organize, augment, and restructure their existing knowledge (Lavoie & Good, 1988).

The Cognitive Nature of Prediction Problem Solving

The prediction process comprises many subordinate cognitive skills such as observing and identifying patterns (McGalliard & Cooney, 1979), inferring rules (Thiel & George, 1976), and synthesizing and evaluating information (McAulay & Camelio, 1976). Prediction is intimately linked with learning, problem solving, and inductive reasoning. For example, learning involves a search for similar and dissimilar patterns (Carnine, 1990) and problem solving is often associated with seeking patterns (Newell & Simon, 1972). The essence of concept understanding revolves around recognizing and categorizing similar and dissimilar examples [patterns] of the concept (Medin & Smith, 1989; Tennyson & Park, 1980). Induction also uses processes of categorization and, through inference, generates hypotheses and predictions (Holyoak & Nisbett, 1988). Mental operations, such as identifying relationships, exploring relationships, differentiating information, and determining cause and effect, are considered characteristic of inductive thinking (Joyce & Weil, 1986), and it follows, prediction.

Prediction can be defined in information-processing terms as a process of combining knowledge of the input state with a causal rule to result in the predicted output state (Carlson, Sullivan, & Schneider, 1989). Causal rules may be represented by "condition-action production rules" of the form: if such and such condition is true, then such and such action should follow. Holland (1985) makes the following comment regarding the relationship between inductive if-then rules and prediction:

Condition-action rules are obviously well-suited for making predictions. A rule that leads to a successful prediction should be strengthened in some way, increasing the likelihood of its use in the future; one that leads to error should be modified or discarded (pg. 16).

It seems likely that if-then production rules may be declarative as well as procedural. For example, successful prediction has been shown to depend heavily on relevant and correct cause-effect declarative knowledge (Lavoie, 1989, April). This research study should reveal the declarative and procedural nature of if-then production rules relative to how they are formulated and applied to make an prediction.

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Methodology

Prediction Problems

Fourteen prediction problem sheets were developed for six different conceptual systems in biology: variation in populations, inheritance, circulation, homeostasis, reflex responses, and ecology. Two problems were developed for each area with the exception of four problems in ecology. Each problem sheet required the student to make a prediction either in writing, or on a graph, and then to explain their reasoning, also in writing. Prediction problems were developed according to several types of formats: system (Ecology), ex-post facto (Variation in Populations), observational (Variation in Populations), and experimental (Inheritance, Circulation, Homeostasis, and Reflex Responses).

The system prediction problem required the subject to predict an outcome that depended on the interaction between several variables in a system. This outcome could not be readily tested or confirmed by direct evidence. For example: predict what would happen to an terrestrial ecosystem if a natural catastrophe was to wipe out all the secondary consumers.

The experimental prediction problem asked the subject to predict the effect of one manipulated variable on one responding variable or outcome. In each case, the manipulated variable was testable through a controlled experiment or event. For example: you decide to shine a light on only one eye of a friend while keeping the unexposed eye in the dark; predict how each pupil of your friend's eye will respond.

The observational prediction required students to predict the outcome resulting from one or more observations or measurements. For example: predict on a graph the pattern of shell lengths you would expect if you measured 100 shells.

The ex-post facto prediction problem instructed the subject to make a prediction concerning multiple variables or the events that would have had to occur to result in a given outcome. For example: predict what may have happened the previous year to have caused a field of daisies to have a higher than average growth rate.

Subjects and Data Collection

At a north central U.S. university, four pre-service students enrolled in a secondary methods class and four pre-service students enrolled in a elementary methods class were randomly selected to solve the prediction-problem sheets during individual videotaped think-aloud interviews (Ericsson & Simon, 1984).

An additional twelve students from each class were randomly selected to solve the prediction-problem sheets silently in class. Students in the secondary methods class were primarily science majors while those in the elementary/middle school class were primarily non-science majors. Both classes were pre-tested with the Group Test of Logical Thinking - GALT (Roadranga, Yeany, & Padilla, 1983) and the Process of Biological Inquiry Test - PBIT (Germann, 1989). A two-group unpaired t-test showed no significance difference between the two groups (GALT, $p = .443$; PBIT, $p = .1364$).

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Qualitative Data Analysis Procedures

Qualitative analysis followed a series of four steps with each step building from the previous step: 1) identification of cognitive behavioral categories associated with successful and unsuccessful predictors, 2) construction of sequential behavioral transcripts for both successful and unsuccessful predictors, 3) identification of cognitive scripts for successful and unsuccessful predictors with attention to procedural and declarative knowledge, and 4) development of a cognitive network model of prediction problem solving.

The cognitive behaviors in step one were identified using techniques of comparative systematic data analysis (Glaser & Strauss, 1967) and verbal protocol analysis (Ericsson & Simon, 1984). All behavioral and evaluation categories were reviewed and modified by a team of science educators.

For each problem, subjects were labeled as "successful" if they made an accurate prediction, or a prediction that could be considered probable or possible, in conjunction with scientifically valid reasoning. Subjects were labeled as "unsuccessful" if, in addition to using partially valid, invalid, or no reasoning, they: 1) made inaccurate or imprecise predictions, 2) made predictions that could be considered improbable or impossible, 3) made an prediction unrelated to the problem, or 4) restated the prediction-problem information as their prediction. Subjects were labeled as "transitional" if they made an accurate or possible prediction, but did not support it with scientifically valid reasoning, or if they made an inaccurate or impossible/improbable prediction but used scientifically valid reasoning. Scientifically valid reasoning required the application of at least one relevant and correct cause-effect relationship to support a given prediction.

High frequency behavioral tendencies associated with successful and unsuccessful predictors were then identified using techniques developed by (Lavoie & Good, 1988). Successful and unsuccessful cognitive scripts were identified from sequentially coded behavioral transcripts. A cognitive script is defined as the sequence of procedural and declarative knowledge behaviors resulting in a prediction. A cognitive-network model was then synthesized from the cognitive scripts.

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Results

The results confirm that successful prediction problem solving involves an intricate network of relevant declarative knowledge that is manipulated and transformed by appropriate procedural knowledge. Students' patterns of predictive success, prediction problem types, cognitive behavioral tendencies, production rules, cognitive scripts, and a cognitive network model of the prediction process are described below.

Patterns Predictive Success

Overall, there were 24% successful and 36% unsuccessful predictions in the elementary/middle school methods class in contrast to 35% successful and 28% unsuccessful predictions in the high school methods class.

Prediction Problem Types

The extent to which knowledge was identified and used varied between different types of prediction problems. In general, the system type and the expost-facto type of prediction problem led to a greater identification of a declarative knowledge base (terms, variables, facts, and relationships) than the experimental type. Several interacting variables and several possible outcomes were characteristic of these problem types.

Cognitive Behavioral Tendencies

Thirty-four cognitive behavioral categories were identified with the silent in-class prediction sheets and sixty two behavioral categories via prediction sheets and think-aloud interviews. A summary of students' procedural-declarative knowledge tendencies for successful and unsuccessful predictors, overall types of problems, is shown in Table 1. Procedural knowledge was characterized by action verbs such as identify, apply, evaluate, and interpret. Declarative knowledge involved terms, variables, facts, and relationships between facts that are used to make a prediction.

Successful subjects were much more likely to identify and apply scientifically correct terms, variables, and causal relationships that were directly relevant to the prediction problem. They tended to correctly apply if-then logical reasoning which involved inducing causal relationships, deducing generalizations from facts and premises, and making accurate predictions. Successful predictors also tended to utilize behaviors commonly associated with metacognition (e.g., planning and self evaluation).

Unsuccessful subjects tended to identify and apply incorrect facts or causal relationships. These behaviors were often identifiable as misconceptions or alternative conceptions. At times, unsuccessful predictors did possess the appropriate declarative knowledge but could not apply it correctly.

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Table 1 Summary of Contrasting Behavioral Tendencies of Successful and Unsuccessful Predictors Overall Problems, Classes, Prediction Sheets, and Think-Aloud Interviews.

**SUCCESSFUL SUBJECTS TENDED TO:
 UNSUCCESSFUL SUBJECTS TENDED NOT TO:**

 Interpret graphs correctly

Interpret the prediction problem correctly

Ask clarifying questions about the problem goals and parameters

Identify and apply relevant information given in the problem

Identify and apply assumptions inherent in the problem to define problem condition

Identify and apply relevant personal experiences

Identify and apply relevant analogies and metaphores

Evaluate declarative knowledge, procedural reasoning, and proposed prediction

Plan future action concerning procedural processes used to make a prediction

Apply if-then logic to induce relevant and correct cause-effect relationships from relevant and correct facts and premises

Apply if-then logic to deduce relevant and correct generalizations from relevant and correct facts and premises

Identify and apply relevant and correct declarative knowledge of terms, variables, facts, and cause-effect relationships to make accurate and probable predictions

Identify and apply quantitative values to make more specific and quantitative predictions

Apply if-then logic to make accurate or probable predictions based on relevant and correct cause-effect relationships

Identify gaps in declarative knowledge given or identified from memory.

Identify errors and inconsistencies of memory based declarative knowledge as well as procedural based logical reasoning

Modify predictions based on repeated analysis and evaluation of procedural and declarative knowledge

Propose and evaluate several alternative predictions

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Cognitive behavioral differences were also evident between students in the elementary/middle and the secondary methods classes. In general, more successful predictors were found in the secondary class. They possessed a greater amount of declarative knowledge of terms, variables, facts, and relationships as well as a greater tendency to use procedural if-then logic. The secondary class also had a greater tendency to use valid reasoning and metacognitive strategies, than the elementary/middle school class.

While in-class prediction sheets were not as effective as think-aloud interviews for identifying the knowledge of individual students, they never-the-less revealed considerable information about the conceptions of the class as a whole.

Production Rules

Declarative knowledge production rules were represented by cause-effect relationships that were applied to justify a prediction. For example, if a predator population is removed from an ecosystem, then the prey population will increase. Cause-effect of this form represents a conceptual understanding based on an explanatory connection between facts.

Procedural if-then production rules represent logical reasoning processes. In some cases they inductively led to prediction. For example, if water causes plants to grow, and plant "A" receives more rain than plant "B," then predict that plant "A" will grow taller. Another production took the form of, if prediction A has more cause-effect evidence in its favor, then choose prediction "A" over alternative predictions "B" and "C." In other cases, productions led to the formation of a concept. For example, if water is used by the plant for the process of photosynthesis; and photosynthesis produces energy for growth; then water is a necessary factor for plant growth.

Cognitive Scripts

A very simplified successful pattern of a typical problem-solving sequence (i.e., cognitive script) was as follows: 1) identification of scientifically relevant and correct terms, variables, and facts, 2) identification of scientifically relevant and correct cause-effect relationships between the facts, and 3) application of if-then induction using the most appropriate cause-effect relationship or relationships to make an accurate prediction. Several other successful as well as unsuccessful variations of this pattern were exhibited. An example of a more detailed cognitive script of successful and unsuccessful prediction are shown in Table 2.

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 Table 2 Typically Cognitive Scripts of Successful and Unsuccessful Predictors Overall
 Problems, Classes, Prediction Sheets, and Think-Aloud Interviews.

Successful Cognitive Script:

Read Problem --> Identify Problem Conditions ----> Define Relevant
 Information Given ----> Search for Additional Relevant Knowledge ---->
 Identify Relevant and Correct Cause-effect Relationships ----> Identify
 Inconsistencies ----> Modify Relationships ----> Apply If-then
 Reasoning ----> Make Prediction ----> Evaluate Prediction ----> Modify
 Prediction ----> Make Final Prediction

Unsuccessful Cognitive Script:

Read Problem ----> Identify Problem Conditions ----> Identify Relevant
 Fact Incorrectly ----> Apply If-Then Reasoning ----> Make Final
 Prediction

Cognitive Model of the Prediction Process

The complexity and intricacy of the relationships and patterns between cognitive behaviors of procedural and declarative knowledge associated with successful predictions are illustrated via a cognitive-network model (Figure 1). This model is an attempt to represent the structure and function of procedural and declarative knowledge relationships necessary for solving prediction problems. Procedural-knowledge goal behaviors (PKGBs) identify, define, describe, and elaborate the declarative knowledge base (DKB). The heart of the model is marked by the procedural-knowledge processing center (PKPC) which includes behaviors that combine, compare, discriminate, and reflect among and between PKGBs and the DKB. Such processes lead to the selective combination, organization, and assembly of relevant connections between and within declarative and procedural knowledge bases. The PKPC may decide to change a solution path after evaluating it as ineffective; to search for, and add, additional information to the network; to reject identified information; and, to develop, explore, and evaluate a new idea. The PKPC is also associated with "thinking about one's thinking" or metacognition. Another essential part of the model is the procedural-knowledge logic center (PKLC). The PKLC, which connects with the PKPC and PKGBs, is driven by inferential if-then logic that applies processes of induction and deduction.

It can be seen that several pathways may be followed and loops may branch several times through the PKPC and PKLC. An individual's pathway through the cognitive network can be represented by a "trace path," or cognitive script. Different cognitive scripts can be identified by following different pathways. Notice that many possible trace paths or cognitive scripts that could be followed to achieve predictive success. In general, successful students tended to access a greater number of cognitive pathways and apply a greater amount of relevant knowledge.

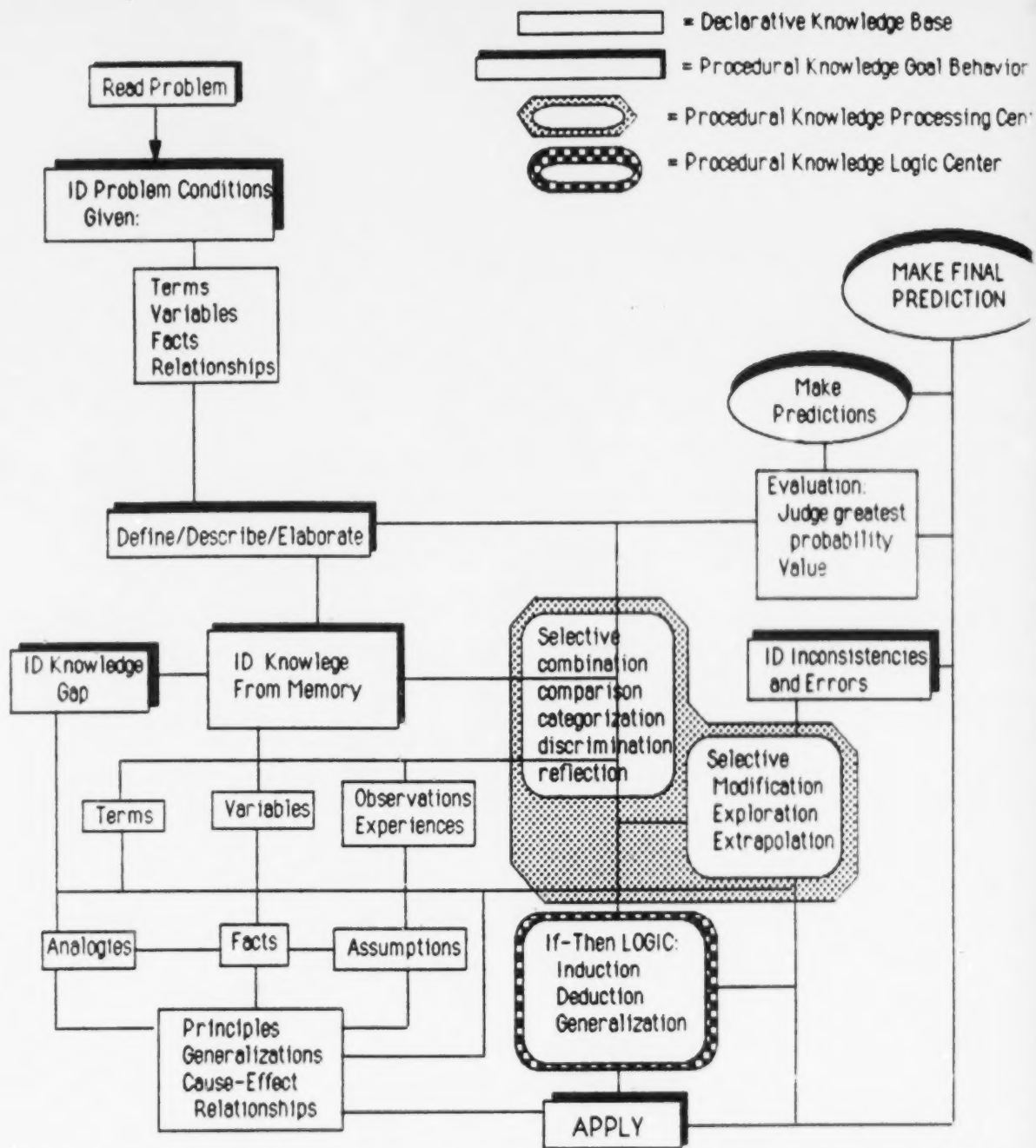


Figure 1. Information processing model of the prediction process.

Discussion and Conclusion

The mechanism of successful prediction problem solving was shown to be dependent upon a complex interplay between procedural and declarative knowledge as illustrated by a cognitive network model. This research represents one significant step toward developing problem-solving teaching strategies that take more advantage of the tremendous potential of "prediction power" in the science classroom. Predictive success, alternative conceptions, prediction sheets, prediction-problem types, cognitive models, and prediction teaching strategies are discussed below.

Predictive Success

Successful predictors were separated from unsuccessful predictors by an ability to apply a rich source of procedural skills in definite patterns (e.g., if-then inductive reasoning) to a declarative-knowledge base (e.g., correct and relevant cause-effect relationships). Interestingly, the primary limiting factor for predictive success tended to be procedural rather than declarative. In many cases, students possessed correct and relevant declarative knowledge but could not apply this knowledge in successful ways to make an accurate prediction. This could be due to either a lack of having established successful connections between the necessary procedural and declarative knowledge, or simply a lack of appropriate procedural knowledge. These deficiencies could be eliminated by giving students experiences solving problems in combination with appropriate intelligent coaching. Perhaps this could account for the greater success of the secondary methods class.

If the goal is to increase problem solving performance, it must be remembered that, "The scissors do indeed have two blades... and...effective education calls for attention to both subject-matter knowledge and general skills (Simon, 1980). Teaching strategies need to be developed which nurture a successful interdependence between both process and product.

Alternative Conceptions and Conceptual Change

This study reaffirms earlier research that prediction is a powerful means for revealing and assessing students' understandings of science (Lavoie, 1989). Students' incorrect identification and application of facts and relationships were often recognized as misconceptions or alternative conceptions. Past research has suggested that having students make predictions followed by hands-on experiments to verify or refute their prediction is an effective conceptual change teaching strategy (Watson & Konicek, 1990). Prediction satisfies some of the essential conditions for conceptual change by:

- (1) allowing students to identify and express their own personal conceptions and providing the motivation for evaluating their worth (Cosgrove & Osborne, 1985; Nussbaum & Novick, 1982),
- (2) requiring students to link prior knowledge with new knowledge (Watson & Konicek, 1990), and
- (3) setting the stage for dissatisfaction or disequilibrium with personal knowledge as a result of evidence refuting a prediction (Champagne, Gunstone, & Klopfer, 1983; Posner, et al. 1982)

Of course, prediction can be used to reveal prior knowledge, motivate, and establish a mental readiness for conceptual changes only to the degree that students are required to make explicit their reasoning associated with a given prediction. Future research should investigate the effects of assigning prediction a central role in conceptual change strategies. Prediction problems that focus on science areas rich in alternative science conceptions should prove most fruitful.

Use of Prediction Sheets

Although not as effective as think-aloud interviews for identifying specific knowledge of individual students, the prediction sheets used in this study quickly assessed students' general knowledge and understanding. Teachers, not having the time to use think-aloud interviews, could administer prediction sheets prior to instruction to assess students' pre-conceptions (alternative conceptions); during instruction to assess students' progress; and following instruction to assess students' learning (e.g., degree of conceptual change). High school science students were found to be quite positive about using prediction sheets and, when encouraged, spent considerable time elaborating their reasoning (Lavoie, 1990). Future investigations should focus various application of prediction sheets in science instruction from a diagnostic, formative, and summative perspective.

Prediction Problem Types

Several factors could account for greater levels of cognitive knowledge and processing being associated with the system and ex-post facto types of prediction problems. The primary factor probably relates to the more divergent nature of these problem types which involved several interacting variables that affected several possible outcomes. Another factor could relate directly to the extent of a students' declarative knowledge base (i.e. familiarity with the subject). Problem structures or content areas with which students have little experience must result in limited information processing. Furthermore, two other factors, cognitive processing speed and capacity of working memory, have been shown to affect problem solving success (Carlson, Sullivan, & Schneider, 1989; Roth, 1989; March; Roth, 1990).

These findings suggest that teachers need to choose the type and structure of prediction problems very carefully. This should depend on students' prior knowledge and experience in a given domain, as well as the teachers' goals for assessment and subsequent student experimentation. Future research is needed to identify and test the effects of different prediction problem types under a variety of conditions relative to the quantity and quality of students' procedural and declarative knowledge.

Cognitive Model of Prediction:

The cognitive network model of prediction constructed by this study expands current views of if-then "production systems" (Anderson & Milson, 1989; Holland, et al. 1985; Klauer, 1989), and further amplifies the important role of "prediction power" in teaching and learning. The network is built up from a procedural knowledge base of cognitive processing behaviors that search for, identify, define, apply, induce, deduce, and evaluate a declarative knowledge base of terms, variables, facts and relationships between facts. Although the model incorporates components of other problem-solving

models such as "IDEAL" (Bransford & Stein, 1984), ACT* (Anderson, Boyle, & Reisen, 1985), triarchic theory (Sternberg, 1985b), and the "structure-of-the-intellect" model (Ouliford, 1976). It is much more specific and detailed. Connections are explicitly identified between the procedural and declarative knowledge components of prediction problem solving. Production rules seem to establish the basic mechanism driving the development and use of both procedural and declarative knowledge. Interestingly, production rules are considered a primary way that knowledge is represented in the brain (Shuell, 1986). Finally, all these connections are intimately connected to the final goal state, making a prediction.

The cognitive network model developed by this research suggest several applications. An attractive generic nature makes it adaptable to many disciplines, not just science, and perhaps to various grade levels. The model may be useful to teachers for determining the structure of prediction problems, evaluating students reasoning, and tutoring students during prediction problem-solving activities. The model may also be useful for developing intelligent computer tutors or expert systems (Good, 1987; Kearsley, 1987; Lippert, 1987). By utilizing facts and heuristics (inference patterns) used by experts (successful problem solvers), expert systems can be programmed to diagnose student's reasoning processes and make intelligent decisions determining the course of subsequent instruction.

It should be understood that the cognitive model described in this study for prediction problem solving is by no means complete. Future research is needed to discover additional connections, behaviors, applications, and dimensions associated with the model. New teaching strategies designed to improve prediction skills, and to take advantage of "prediction power" for enhancing learning, in general, need to be developed and tested in the science classroom. The use of the cognitive network model in developing a prediction teaching strategy is described below.

Teaching Prediction Problem-Solving:

Prediction problem solving is a complex process that can be taught from a cognitive science constructivistic perspective. Constructivists have argued that students must actively construct their own understanding of a concept to meaningfully understand and apply that concept (Pines & West, 1986; Potts & St John, 1989; Shymansky, 1989, March). It follows that students must actively construct their own knowledge in increasingly complex networks in order to solve increasingly complex problems. Students must become comfortable grappling with their own inconsistencies, knowledge gaps, and weaknesses in logic.

Instructional strategies could be devised that strengthen and define successful connections between appropriate procedural knowledge behaviors and a correct and relevant declarative knowledge, while discouraging unsuccessful connections. On a basic level, a teacher very familiar with cognitive behavioral tendencies could promote successful behaviors and discourage unsuccessful behaviors. On a higher level, a teacher could emphasize successful cognitive scripts and discourage unsuccessful scripts. On a still higher level, students could be encouraged to build a predictive framework, or network, of successful cognitive scripts.

The cognitive prediction model described in this paper suggests several successful scripts that could be encouraged in students as well as unsuccessful scripts that could be discouraged. An Explicit Prediction Teaching Strategy (EXPTS).

developed from these scripts, is currently being tested by the author. EXPRTS encourages students to organize and structure successful cognitive scripts and explicitly emphasizes the interrelationships between procedural and declarative knowledge bases for the purpose of developing a more successful and elaborate prediction problem-solving framework. A typical problem-solving script strengthened by EXPRTS might involve the following sequence:

- 1) Identify all information given in the problem (terms, variables, facts, etc.).
- 2) Identify all possible terms and variables associated with the prediction problem.
- 3) Define all terms and variables in as much detail as possible.
- 4) Compare, combine, categorize, and discriminate the facts to identify relevant cause-effect relationships.
- 5) Identify any gaps in knowledge (questions) and take steps to remedy the situation.
- 6) Recall any relevant experiences similar to the prediction problem situation.
- 7) Identify any analogies that are relevant to the prediction problem.
- 8) Identify and reflect on errors and inconsistencies in logic or knowledge.
- 9) Select, evaluate, and modify relevant cause-effect relationships.
- 10) Use if-then deductive logic to put forth several possible predictions based on relevant and correct declarative knowledge.
- 11) Evaluate and modify predictions through selective combination, comparison, categorization, and discrimination.
- 12) Evaluate and select the most probable prediction.
- 13) Reflect on cognitive procedures employed and modify if necessary.

Metacognition, considered the highest form of thinking and learning, involves mental processes of self-awareness, self-monitoring, and self-regulation (Holliday, 1989, March). Sternberg (1985b) recognizes metacognition in the form of metacomponents which include planning, monitoring, and evaluation processes. The successful "reciprocal teaching" teaching technique of Palincsar and Brown (1984) relies extensively on the application of comprehension fostering and comprehension monitoring activities. EXPRTS manifests such metacognitive behaviors in the form of evaluation, modification, planning, and reflection.

Researchers have argued that instruction needs to be made more explicit and directed (Sogal, Chipman, & Glaser, 1985). Previous efforts that directly teach problem solving behaviors have proven productive in some cases (Larkin, 1980; Nickerson, 1987). Perkins (1987) actually advocates teaching "frames" or thinking tactics explicitly, or provoking students to invent their own frames. Obviously, extensive practice with a variety of problem types are also requisite for improving problem

solving success (Fisher & Lipson, 1983; Helgeson, 1990). Carlson (1989) notes that "practice should increase the efficiency with which procedural skills operate on information in working memory." Practice with a focus on the application of procedural knowledge to declarative knowledge should lead to greater "proceduralization," a process which builds domain-specific declarative knowledge into productions (Anderson, 1987).

Teachers need to recognize that the success of a prediction, per se, need not be the focus of instruction. Rather, emphasis should be placed on developing predictive frameworks of successful cognitive behavioral patterns. Lesgold (1988) comments that:

Competent individuals can be described as having knowledge that is organized into a fast-access pattern recognition or encoding system that greatly reduces their reliance on the vagaries of declarative knowledge. These acquired knowledge patterns [productions] enable them to form an appropriate representation of the problem situation [problem space]. (pg. 202)

Teachers also need to realize that teaching problem-solving skills is going to be time consuming process (Anderson & Armbruster, 1982). This implies that the traditional imparting of vast quantities of information, as characteristic of science textbooks, can no longer be the focus of science teaching.

Integrating Prediction

More "prediction power" can be achieved by combining prediction with effective science teaching strategies. It is a natural inclination, following a prediction, to seek out additional information that will support your prediction. Logically, the greater the degree of cognitive commitment, the greater will be this desire. Adding prediction to the beginning of the learning cycle, followed by an exploration phase in which students conduct tests to confirm or refute their prediction, has been shown to have significant positive effects on students' scientific attitudes, logical thinking skills, and motivation (Lavoie, 1990). Prediction can easily be incorporated with cooperative learning strategies (Hendrick, 1988; Johnson & Johnson, 1984; Slavin, 1990). For example, student groups could first develop their "best" prediction and debate with opposing predictions from other groups. Groups could then work together to devise and carry out experiments that would test their prediction.

Summary

It is a challenging educational goal to improve students' problem-solving skills so they can contribute to continued growth and improvement of the human condition. Prediction represents a very important scientific process and problem-solving skill that deserves greater attention from science teachers and science education researchers. Improving prediction problem-solving skills can lead students toward a greater understanding, application, and appreciation of the scientific process.

This research examined details of the prediction process and suggested ways to improve students prediction problem-solving abilities. Different prediction problem formats facilitated different kinds and magnitudes of information processing. Successful prediction was found to depend on both declarative and procedural production systems that generated, manipulated, represented, and applied correct and relevant declarative knowledge. A cognitive network model of the prediction problem-solving process was constructed based on students' behavioral tendencies and

scripts. The model suggests an explicit prediction problem-solving instructional strategy that is currently under investigation.

This prediction research has opened the door, albeit slightly, to an extremely intricate thinking mechanism. Future research could swing this door open wider and give teachers entree to an information-processing revolution in science teaching and learning. New cognitive science teaching tools must be devised which can efficiently connect students previously "inert" knowledge with new "meaningful knowledge" in ways that facilitate the application of that knowledge to important problems. Perhaps, using more explicit methods to teach prediction problem solving will instill in students the idea that information is to be connected and applied, not just memorized for a test. Perhaps, students can be led to construct significant changes in their thinking processes, to become more aware of how such changes come about, and ultimately, to better facilitate their own cognitive changes. Science teachers may find that their students liking and desiring science. The association between science and "nerd" will gone forever. WOW!

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